Spatio-temporal patterns of large grassland fires in the Intermountain West, U.S.A.

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Abstract:
The spatial and temporal occurrence of large grassland fires (>2008 ha) in the Intermountain West was examined for the period 1980 through 1995. Results suggest that these fires are largely predictable through space and time. Of the 360 large fires, 339 occurred within eight regions as defined by clustering of fires within physiographic boundaries. These regions were characterized by their abundance of exotic annual grasses and flatter terrain that provided continuous fine-fuel conditions that promoted fire spread. Temporally, the likelihood of a large fire is correlated with summer moisture conditions (Z-index values) in the year preceding that of the fire that are either
near-normal or wetter. Conversely, <20% of all the large fires occurred when the previous summer's Z values were below normal. This may be explained by enhanced fine-fuel build-up enabled by mesic conditions, causing increased biomass in the following summer and thus increasing the incidence of large fires. Moisture conditions in the summer in which the large fires occurred appeared to have less influence on the likelihood of those fires.
Key words: Intermountain West U.S.A., grassland fires, fire occurrence, fire prediction, exotic annual grasses, Palmer's Z-index values.

Article:

INTRODUCTION

The expansion of exotic annual grasses (e.g. Bromus tectorum L. and Taeniatherum asperum L.) into the Intermountain West of the U.S.A. has substantially changed fire patterns, creating an environment where fires are easily ignited, rapidly spreading, and large (Pellant, 1990). Additionally, because grassland fires were less frequent prior to the introduction of exotic annuals (Mack, 1981; Billings, 1994), these fires exert a significant ecological pressure on native shrubs and grasses (that did not evolve with frequent fires) by altering successional processes (Young et al., 1987; West, 1994) and decreasing species diversity within the burned area (Whisenunt, 1990). Further, post-fire conditions leave areas temporarily susceptible to soil erosion, reduce wildlife populations (Roberts, Jr, 1990; Yensen et al., 1992), and preclude grazing by domestic livestock for at least two growing seasons (Pellant, 1990).

Rangeland wildfires involving resource losses, pre-suppression, suppression, fire management, and rehabilitation, are also costly (Arno, 1996; Knapp, 1996). Thus, there is a great impetus to limit their frequency and areal extent. One means of fire management in the U.S.A. has been to employ predictive models to forecast when and where fires will occur. Most of the models (e.g. the National Fire Danger Rating System, the Lightning Locating and Fire Forecasting System, and the Fire Behavior Prediction System) are not designed for long-range forecasting, but range from real-time (1-2 days) to short-term trends of 15-30 days (Bradshaw et al., 1983; Latham, 1983; Rothermel et al., 1986). While short-term model effectiveness is based largely on weather observations, fuel moisture amounts, topography, fuel density and fuel type, longer-range models have concentrated on examining the influence of antecedent climatic conditions (several months prior to the fire) that are either conducive to fine-fuel buildup (e.g. Knapp, 1995) or which influence fuel mosture conditions (e.g.

Balling, Meyer & Wells, 1992a,b). No long-range fire forecasts, however, have integrated fire probabilities based on preferred areas and dates of ignition, although distinct spatial patterns of fire occurrence exist in the West (e.g. Vankat, 1985; Knapp, 1997), and numerous studies (e.g. Groves & Steenhof, 1988; Whisenant, 1990; Yensen et al., 1992; Peters & Bunting, 1994) have addressed the ecological consequences of large fires that *repeatedly* burn within a defined region (e.g. the Snake River Plains area of Idaho, U.S.A.).

Grassland fires in the Intermountain West predominantly occur between 1 June and 15 September (in Knapp, 1995). There is, however, substantial variability in fire size, location, and ignition date. Fire size is recorded initially by an incident commander as acreage burned, but also is classified into fire class groups: A (0-0.8 ha); B (>0.8-4.0 ha); C (>4.0-40.2 ha); D (>40.2-120.4ha); E (>120.4-401.6 ha); F (>401.6-2008.0 ha); and G (>2008.0 ha). The majority of fires are small (<4 ha), but despite their frequency, they collectively represent <1% of the total acreage burned. Conversely, G-class fires (>2008 ha) are infrequent, but represent >70% of total area burned, thus, their impact is large, and range-management decisions could be enhanced, if the conditions that promoted these fires were understood better.

The purpose of this study is to address whether large fires (class G) are predictable based on spatial and/or temporal patterns of occurrence during the period 1980 through 1995. Specifically, this paper will show: (1) that distinct spatial patterns of large fires exist; (2) when fires are most likely to occur (or not occur) based on antecedent moisture conditions; and, (3) why these areas are more likely to burn.

STUDY AREA

The study area comprises approximately 700,000 km2 (Fig. 1; Knapp, 1997). The physiographic characteristics are dominated by basin and range topography, except for the Snake River Plain in southern Idaho, and the variable terrain of northeast Oregon (Raisz, 1954; Trimble, 1989). Base elevations are highly variable, from near sea level along the Columbia River to approximately 2000 m asl in central Nevada valleys. Annual precipitation decreases southward from 25-50 cm north of 41°N, to <25 cm between 41°N and 36°N (Houghton, 1969). Precipitation events are often caused by Pacific-origin fronts during all seasons except summer, when convective thunderstorms dominate, especially east of 115°W (Knapp, 1994).

Three distinct vegetation zones exist within the Intermountain West that may support significant grass cover. The shadscale (Atriplex confertifolia (Torr. & Frem.) Wats.) zone, typically with <20% plant cover, is the most arid community within the region, typically occurring in the lowest areas of the Great Basin, including the Lahontan Trough and Bonneville Basin (West, 1983a). This association is shrub-dominated with little perennial grass cover, but in disturbed areas annual grasses such as Bromus tectorum may be present (Young & Tipton, 1990) and shrub dominance decreases. The sagebrush—desert association is found in either more mesic or less saline environments than the shadscale zone and occurs almost exclusively south of 42°N (West, 1983b). This zone, where absolute cover ranges from 10 to 40%, also occurs under a climate regime too arid to support significant (i.e. >30% relative cover) perennial grass cover (West, 1983b). Under more mesic conditions, generally found north of 41°N, the sagebrush—desert association is replaced by the sagebrush—steppe zone. Cover of perennial bunchgrasses (e.g. Idaho fescue Festuca idahoensis Elmer., bluebunch wheatgrass Agropyron spicatum (Pursh) Scribn. & Sm., and needle grasses Stipa spp.) is greater than the other vegetation zones, with approximately equal coverage between grasses and shrubs (West, 1983c). Total absolute cover on relict sites ranges from >80% to approximately 200% (West, 1983c). As in the other two zones, exotic grass cover can be extensive in disturbed sites, particularly after a wet winter.

DATA AND METHODS

Fire data, provided by the National Interagency Fire Center (NIFC), represented all recorded fires from 1980 through 1995 for seventeen Bureau of Land Management (BLM) districts: Susanville (CA); Boise, Burley, Idaho Falls, and Shoshone (ID); Battle Mountain, Carson City, Elko, Ely, and Winnemucca (NV); Burns, Lakeview, Prineville, and Vale (OR); and Cedar City, Richfield, and Salt Lake (UT). For analysis, fire data were selected from the original data set based on the fuel model types (each fire is identified by the vegetation [fuel model] that burned) that were classified as 'Grass-Dominated' (Anderson, 1982). Four fuel models (based on species composition and relative abundances of grasses) were included: (1) western annual grass; (2) western perennial grass; (3) open pine with grass; and, (4) sagebrush with grass. Data on the number of fires, ignition date, latitude and longitude of ignition site, area burned, climate classification, fuel type (% of annual v. perennial grasses burned), elevation, slope, and aspect, constitute the data set used for analysis and no further distinctions were made between fuel model types.

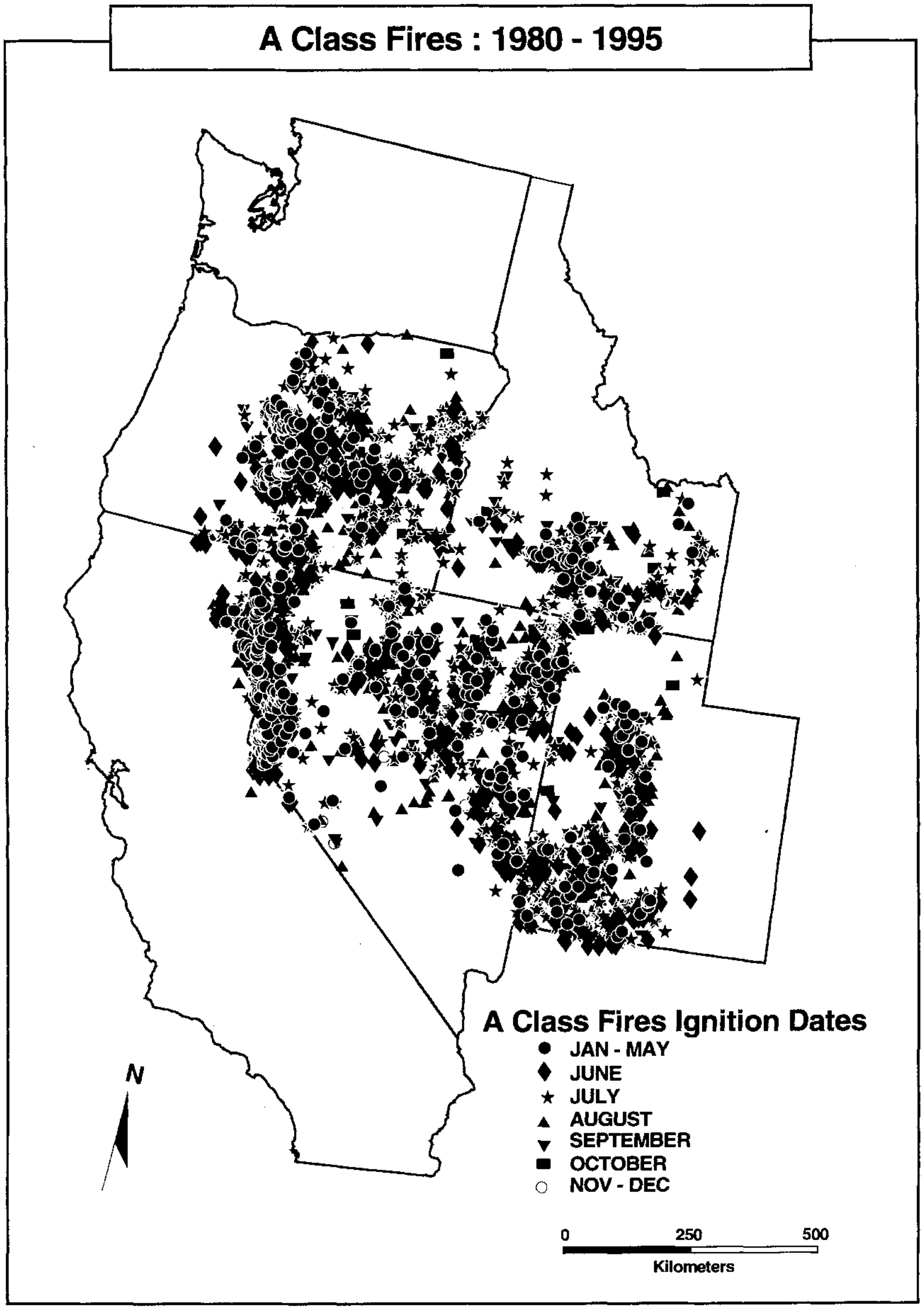

Fig. 1. Location and monthly occurrence of A-class (<0.08 ha) fires in the Intermountain Region between 1980 and 1995.

Fire data were separated into three selected groups based on size class values (area burned) recognized by NIFC: (1) A-class fires that burnt areas less than 0.08 ha; (2) D-class fires that burnt areas between 40.2 and 120.4 ha; and, (3) G-class fires that burnt areas greater than 2008 ha. Fires that fell within these groupings, used as proxies for minimum, median, and maximum size fires, were then mapped and identified by month of ignition (Figs 1 and 2). G-class fires were further separated into eight regions (Honey Lake, Harney Basin, Wasco, Santa Rosa, Owyhee, West Snake River Plain, East Snake River Plain, and Bonneville) based on two criteria: (1) by identifying clusters of fire occurrence; and then, (2) by relating fire location to physiographic provinces (Fig. 3). Fire occurrence/topographic positioning was done by overlaying G-class fire occurrence on a physiographic map (Raisz, 1954) and then noting cluster positions in relation to major physiographic boundaries (e.g. plains, plateaus, large basins, and major mountain ranges).

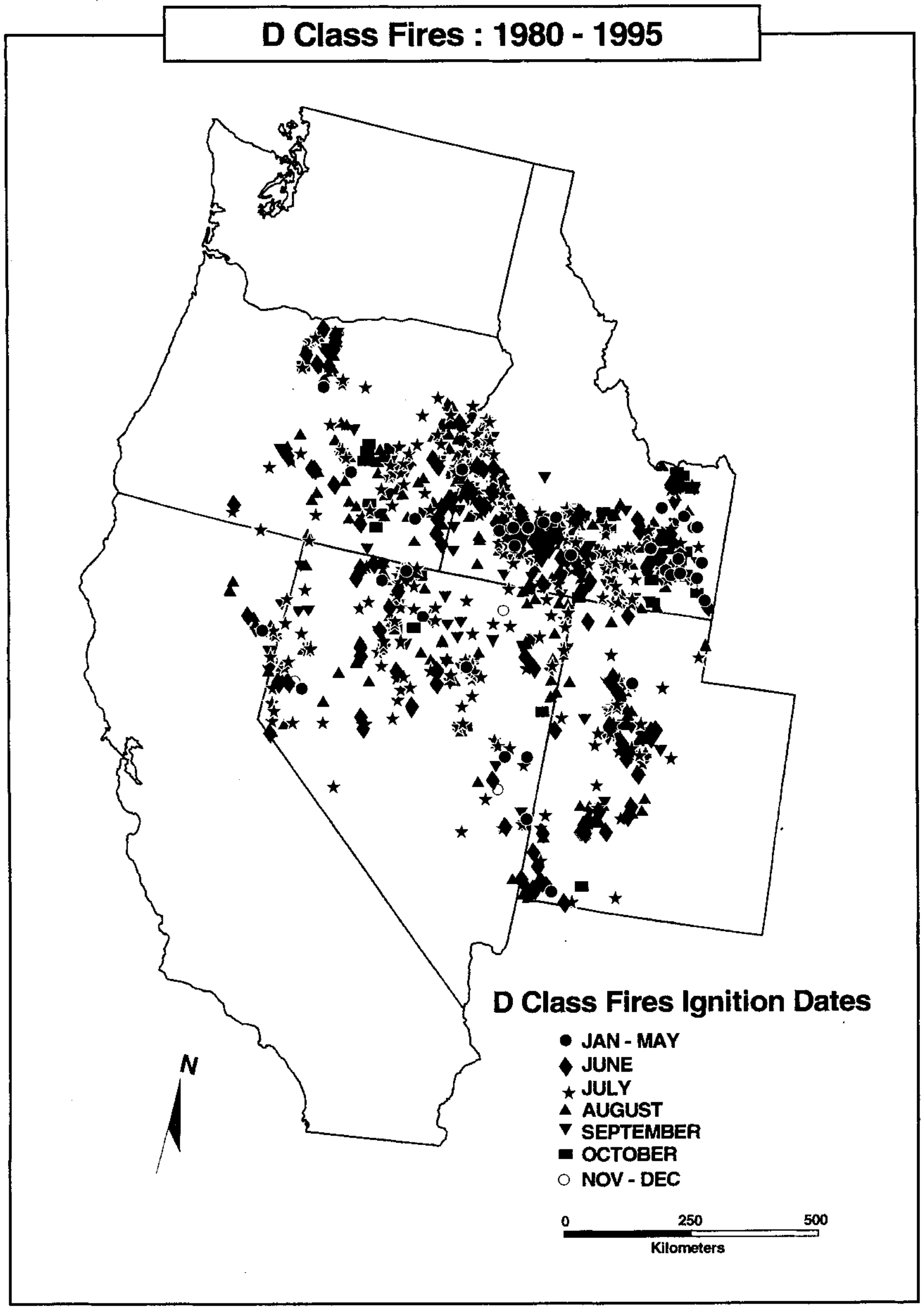

Fig. 2. Location and monthly occurrence of D-class (40.2–120.6 ha) fires in the Intermountain Region between 1980 and 1995.

Raisz maps are widely recognized as exemplary detailed physiographic diagrams of the U.S.A. They have been duplicated and appear in numerous books since the 1930s showing physical landforms (Dent, pers. comm. 1998). Of the 360 G-class fires, 339 (91%) fell within a definable region (i.e. clustering occurred within a physiographic province). The remaining fires were classified as outliers and were not used for analysis. Some of the eight region boundaries may appear arbitrary, such as the distinction between the West Snake River Plain and East Snake River Plain, but this boundary represents a physiographic change from the flat, wide, southwest to northeast orientation of the East Snake River Plan to the substantially narrower, hillier, southeast to northwest orientation of the West Snake River Plain. Similarly, other cluster boundaries were defined by physiographic characteristics (e.g. Harney Basin v. Owyhee upland) where there was little distance separating boundary lines.

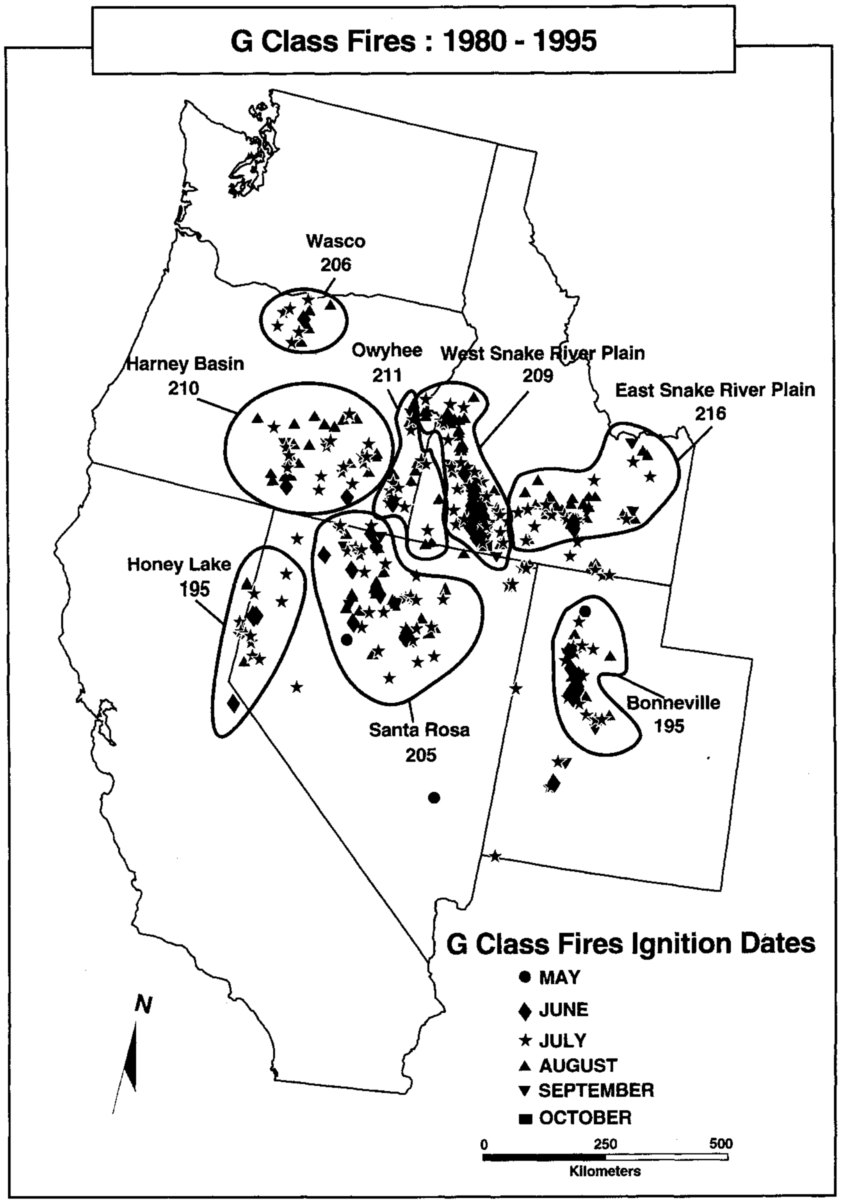

Fig. 3. Location and monthly occurrence of G-class fires (>2008 ha) in the Intermountain Region between 1980 and 1995 by region. Numbers next to regions represent median ignition date (Julian Day) for fires.

Table 1. Fire characteristics for selected size classes of fire in the Intermountain West, U.S.A.: 1980–1995.

	Size class		
	A	D	G
	(<0.08 ha)	(40.2–120.6 ha)	(>2008 ha)
Total area burned (ha)	157	65853	2259870
Area burned (% of total)	<0.01	2.05	70.4
Total number of fires	6968	967	360
Mean annual grass[a]	35.0	60.5	71.4
Mean elevation (m)	1524	1402	1341
Mean climate classification[b]	1.4	1.25	1.25
Mean latitude (°N)	41.2	42.1	42.3
Mean longitude (°W)	117.6	115.7	116.2
Ignition date range (Julian Days)	5–361	71–319	145–288

[a]Percentage of fires where annual grass species represented >50% herbaceous cover.
[b]Based on National Fire Danger Rating System's climate classification (see Bradshaw *et al.*, 1983) using Thornthwaite's (1931) humidity provinces. Values range from 1 (arid and semi-arid) to 4 (wet).

Palmer Z index values (ZNDX) were used to assess moisture conditions that influenced G-class grassland fire occurrence within the selected eight regions. A Z value represents a monthly moisture anomaly within a U.S. climatic division that 'expresses ... from a moisture standpoint the departure of the weather of a particular month from the average moisture climate of that month' (Karl, 1986; p. 78). An advantage of Z values is that they are sensitive to short-term fluctuations in moisture conditions, and thus are capable of indicating a wet/ dry period during an extended drought/wet period. Thus, Z values have been proposed as the preferred moisture index for assessing forest-fire potential (Karl, 1986). Z values range from >3.5 (extreme wetness) to < — 2.75 (extreme drought) and all values fall within one of seven moisture-descriptive categories (see Karl, 1986). The eight fire regions identified generally matched climatic division boundaries, thus Z values were viewed as proxy estimates of moisture conditions. Z value averages were based on standard climatologically-defined seasons (cf. Knapp, 1994) with summer, for example, consisting of the mean of June, July, and August.

G-class fire frequency and antecedent seasonal Z values were examined to determine if significant temporal relationships existed between them. Based on this analysis, summer Z values were chosen, from both the summer before the fire (lag year) and the actual fire year (fire year). The percentage of fires for each region falling within each Z-value category (e.g. extreme wetness) were calculated based on Z-value conditions present the previous year. Thus, the distribution of fires occurring under any particular moisture condition of the previous summer was represented. Additionally, a superposed-epoch analysis (SEA) was created for each region and the mean of the eight reasons. This presentation of results, modified from methods defined by Baisan & Swetnam (1990) and Swetnam (1993), involved two steps. First, the data were separated, by region, into two groups based on whether a fire(s) occurred during the fire season. Thus, each region had both 'fire year ' and `non-fire year' data. Second, fire year (or non-fire year) data were 'superposed' over mean Z values and one-year lagged mean Z values for the corresponding years. Difference of means tests (Student's t) were applied to each grouping, by region, to determine significance of Z value conditions between fire years and non-fire years (e.g. to determine if the one-year lagged mean Z value of Harney Basin is significantly different between the fire year and non-fire year groups).

Table 2. Selected characteristics for each region: 1980–1995. Details of variables as in Table 1.

	Bonne-ville	Harney Basin	Honey Lake	Owyhee	Santa Rosa	SRPE	SRPW	Wasco
Total area burned (ha)	247912	245303	103910	146328	416670	382469	529523	36761
Total number of fires	37	40	20	27	62	48	94	11
Mean annual grass	89	70	40	48	58	81	93	54
Mean elevation (m)	1550	1402	1612	1128	1503	1427	1073	552
Mean climate classification	1.2	1.10	1.7	1.0	1.7	1.08	1.02	2.0
Mean ignition date (Julian Days)	194	210	192	212	206	216	209	206

RESULTS

Differences in fire characteristics based on fire size class were most pronounced for total area burned, number of fires, annual grass cover, mean elevation and ignition date range (Table 1). G-class fires were infrequent, occurred in areas dominated by annual grass over, burned at lower elevations, and were confined to a smaller fire season when compared to either A- or D-class fires (Table 1). Spatial patterns also varied considerably between fire class sizes. A-class fires were widespread with greatest frequencies along the east side of the Sierra—Nevada/Cascade Mountains and in southwestern Utah (Fig. 1). D-class fires were most concentrated along Idaho's Snake River Plain (Fig. 2), while G-class fires occurred in more physiographically discrete regions (Fig. 3). Variability between the eight regions identified in Fig. 3 was most pronounced for occurrence of fires dominated by annual grass cover and mean ignition date (Table 2).

Antecedent (one year lag) summer Z conditions for fire years are dominated by near normal to wet conditions for all the regions (Fig. 4a—i), and >50% of the large fires in the Harney Basin, Santa Rosa, and Wasco regions occurred when the preceding summer moisture conditions were above normal. As a group, 47% of all fires occurred when preceding summer Z values were above near normal (Fig. 4i). Conversely, large fires were uncommon when preceding summer moisture conditions were below near-normal, with percentage occurrence of total fires ranging from 0% at Honey Lake and Wasco to 31% at East Snake River Plain.

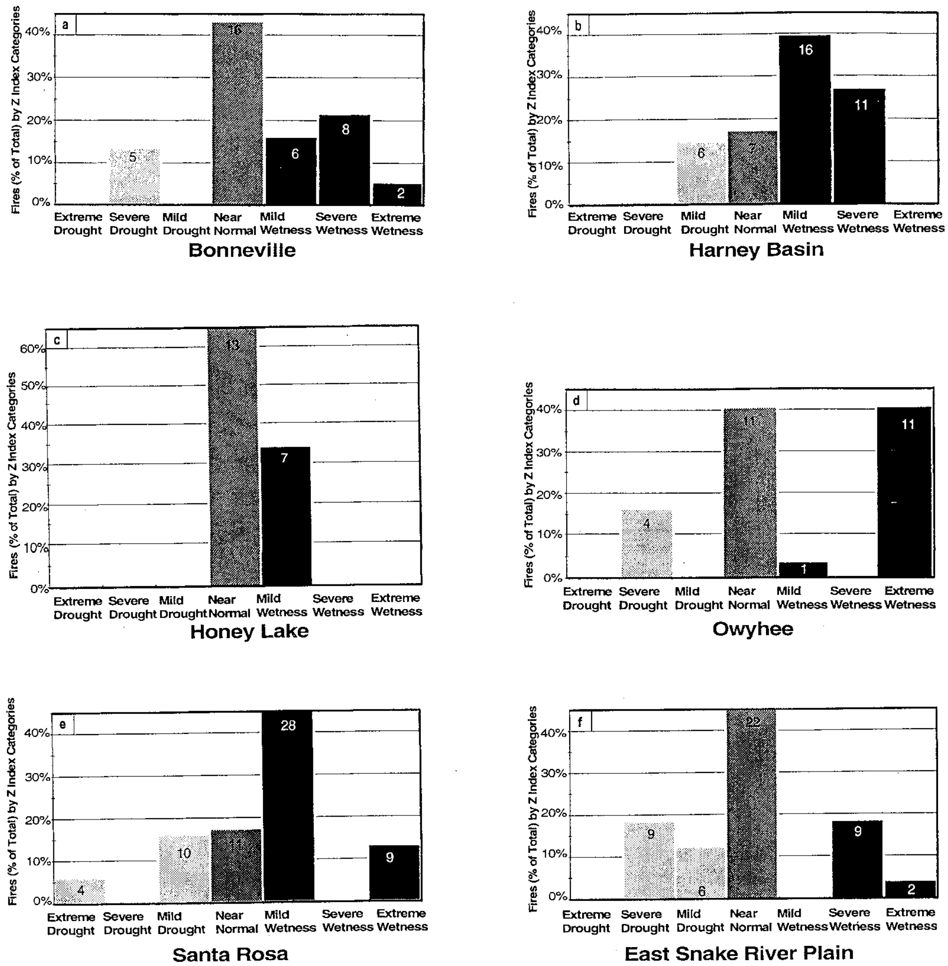

Fig. 4a–i. Frequency (%) of fires occurring within each descriptive category based on mean Z-value scores of the previous summer. Numbers within histogram blocks represent actual numbers of fires occurring based on prior summer mean Z scores.

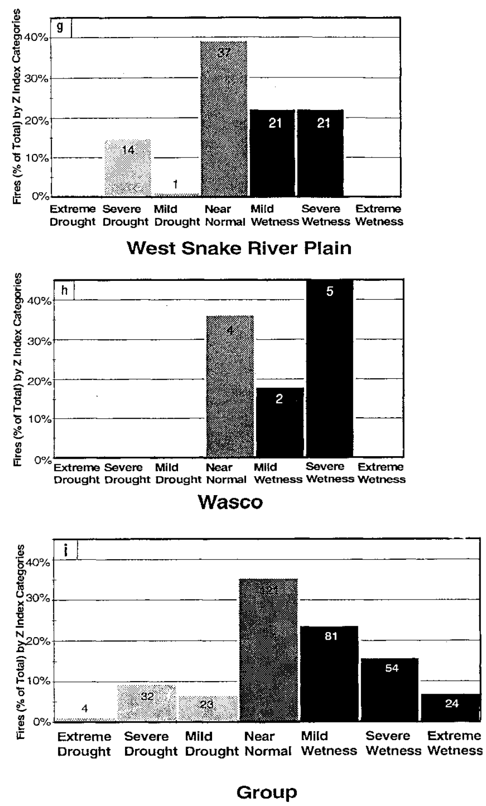

Fig. 4a-i. *contd*

SEA charts (Fig. 5a—i) show that lag-year Z values were positive for all eight regions for fire years, indicating that moisture conditions for the summer preceding the fire year was near-normal or above normal. This relationship was reversed when examining lag-year summer Z values in non-fire years. Here, Z values were negative, indicating drier conditions, in all regions except East Snake River Plain. Comparing lag-year summer mean Z values in fire years with non-fire years revealed significant differences (Student's t, $P<0.05$) for seven regions (the exception was East Snake River Plain), which suggests that a pattern of wet preceding summers favours large fires the following summer, while dry antecedent summers are inconducive for large fires the following summer (Fig. 5a—h). Z-value conditions during the actual fire year do not exhibit a dominant pattern, with three regions (Bonneville, Owyhee, and West Snake River Plain) having positive Z values, while the remaining regions had negative Z values. In comparison, for non-fire years, six of eight regions had positive Z values. Mean summer Z values in fire years were significantly different (Student's t, $P<0.05$) from non-fire years for six of the eight regions (Fig. 5a—h).

All but two G-class fires (<1%) occurred after May and <6% after August. The peak frequency period was July and August, representing >82% of all the fires. A-class fires, conversely, occurred over more of the year, with 7% occurring before June and 15% occurring after August. Approximately 71% of A-class fires were ignited in July and August. Median fire dates show that peak fire periods occurred earliest in the south and then became more common later in the summer in the more northern regions (Fig. 3).

DISCUSSION

This analysis of fire distribution within the Intermountain West between 1980 and 1995 suggests that favourable conditions for large fires are generally present in only a few areas. The primary factors conducive to G-class fire occurrence appear to be flatter areas (i.e. basins and foothills) that are dominated by annual grass cover. These areas, because of their flatter terrain and proximity to perennial water sources, have been used intensively for ranching and agriculture, making them, perhaps, more susceptible to the invasion of exotic annual grasses. Comparisons of topographic conditions where ignition occurred show that >50% of all G-class fires were on flat terrain while <40% of A-class fires were initiated on flat terrain. In addition, these regions represent larger continuous areas of sufficient fine fuels that are required for large fires to occur (Christensen, 1993; Knapp, 1997).

Average annual grass cover for all eight G-class regions exceeded the mean for A-class fires, and in several instances, (e.g. Bonneville, East Snake River Plain, West Snake River Plain) fires occurred almost exclusively in annual grass-dominated communities. Hence, although probabilities of ignition are comparable or are substantially greater in other portions of the Intermountain West (cf. Knapp, 1997), these eight regions appear to represent the optimal combination of fuel amounts and fuel continuity for large fires.

The importance of antecedent moisture conditions has been increasingly linked to fire occurrence in the North American West. Fire occurrence in both grasslands (Minnich, 1982; Rogers & Vint, 1987) and forests of southwest U.S.A. (Swetnam & Betancourt, 1990; Grissino-Mayer, 1995; Swetnam & Baisan, 1996) are linked to moisture conditions within the preceding year(s) of wildfire ignition. Similarly, in Intermountain West grassland communities, Knapp (1995) determined that antecedent precipitation conditions (particularly the prior summer) were significantly related to area burned. These findings all suggest that antecedent moisture conditions 'set the stage' by allowing fine fuels to accumulate to the point where fires carry easily.

Results from the present study suggest that large-scale fires are also strongly linked to the previous summer's moisture conditions. Greater than 80% of all G-class fires occurred when moisture conditions during the previous summer were near-normal or above. Wet conditions decrease the probability of fire, thereby allowing more phytomass to accumulate in that and the following year. These conditions, in turn, provide sufficient fuel for fire to carry during the fire season (Knapp, 1995). The importance of the one year lag is partially linked to continually low atmospheric moisture conditions predominant within the Intermountain region. Under these conditions, grass biomass decomposes slowly (Young et al., 1987), and in the absence of grazing, grass biomass during the actual fire season may represent two growth cycles. Thus, it appears that two years of fuel accumulation is optimal for grassland fires.

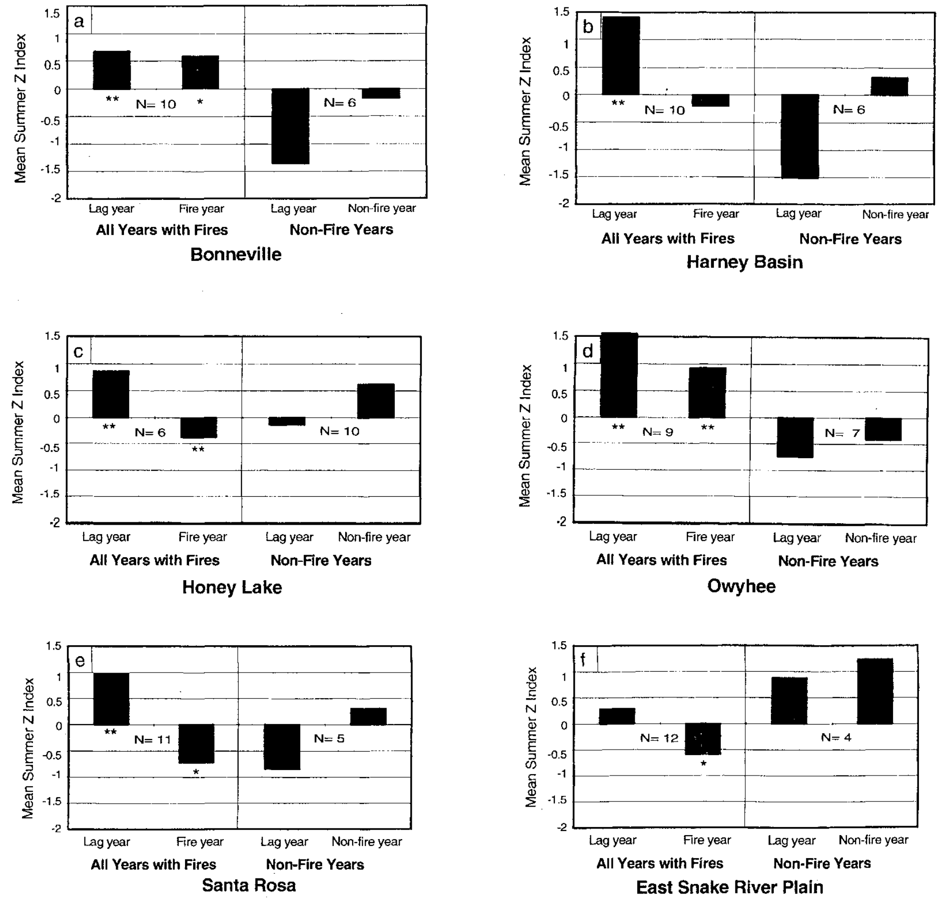

Fig. 5a–i. Mean summer Z index for years with fires (one-year lagged and fire year) and non-fire years (one-year lagged and non-fire year) by regions and as an average of all regions (group). **(P<0.01) and *(P<0.05) are significance levels for difference of means tests when comparing years with fires (lag and fire year mean summer Z values) with non-fire years (lag and non-fire year mean summer Z values), respectively. N values represent number of years with fires or absence of fires.

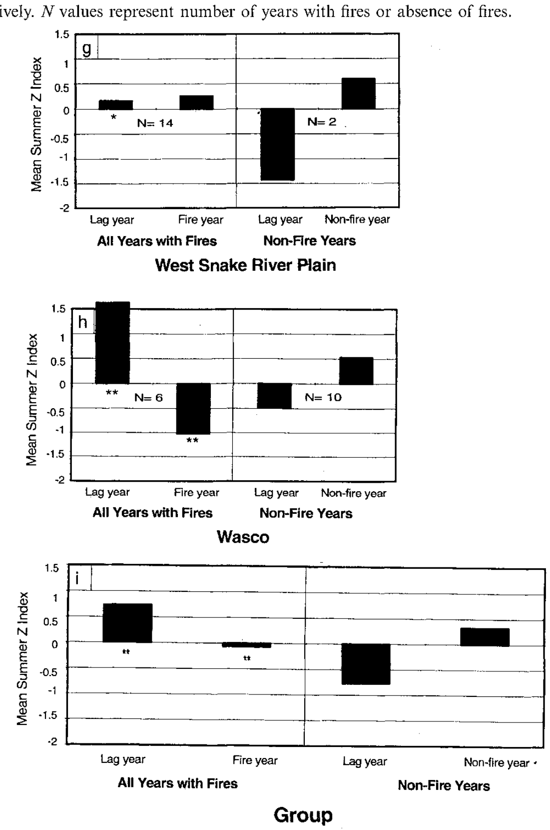

Fig. 5a–i. *contd*

Antecedent summer conditions are better indicators of when fires are unlikely to occur than when they will occur. Less than 20% of the 339 fires occurred if the previous summer was dry, again suggesting the importance of a fuel-amount threshold. The prediction of fire probability is complicated because, even though favourable antecedent conditions may exist, a successive wet (or normal) summer may decrease the chance of fire. Conversely, a previous dry summer is unfavourable to the accumulation of fine fuels, and fires the following year are less likely regardless of summer moisture conditions. It is easier, therefore, to predict when fires are less likely to occur than when they will occur.

The lack of consistent regional pattern in Z-value scores during the actual fire season suggests that the importance of fuel moisture conditions is secondary to fine-fuel amounts in controlling the occurrence of large fires. Similar patterns have been observed in fire-scar dates of trees (after 1790) in northwestern New Mexico (Grissino-Meyer, 1995) while Swetnam & Baisan (1996) found that forest fires in the Southwest U.S.A. were linked to both antecedent-wet and fire-season drought conditions.

Large fires are more temporally constrained than small fires and are infrequent before May and after August. Whereas >22% of A-class fires occurred outside the June to August fire season maxima, <7.0% of G-class fires occurred in the same period. Fire-class size differences in fire dates may reflect micro-scale variability within the Intermountain region where certain sites are 'fire-ready' early or late in the season, but represent areas too small for large continuous fires. Conversely, latitudinal variability in peak fire periods for G-class fires may reflect numerous climatological conditions. These include the onset of warmer (hence, reduced fuel moisture) conditions, associated with peaks in solar radiation receipt, and synoptic-scale changes in prevailing wind directions that facilitate fire spread (e.g. Minnich, 1982).

Although data analysis in this paper is based on the period 1980-1995, 1996 fire data have subsequently become available. Noteworthy is that two large fires, one in the East Snake River Plain region and one in the West Snake River Plain region, occurred during the 1996 summer fire season. These fires would rank first and third in size, respectively, of all fires included in the 1980-1995 data set. Their characteristics are consistent with the previous analysis of what favours both the timing and location of G-class fires. Chiefly, the mean summer Z-values in the summer preceding these fires (1995) were rated as extreme wetness and severe wetness. Both fires occurred on flat terrain, burned in either July or August, and had a fuel model classification of sagebrush with grass.

CONCLUSIONS

These results must be treated cautiously since they represent a brief study-period, and the combined effects of fire suppression, grazing, and other land-use policies were not accounted for in the analysis. That said, the results suggest that large fires within the Intermountain West of the U.S.A. are largely predictable in terms of location and time. Spatially, nearly all the fires occurred within eight regions representing approximately 60% of the overall area, and were most common in large, continuous flat areas dominated by exotic annual grasses. Temporally, wet or near normal antecedent summer moisture conditions, allowing fuel build-up, appear to control fire frequencies in the following summer. Absence of favourable antecendent moisture conditions greatly decreases fire occurrences. Peak periods of fire occurrence shift latitudinally from the south towards the north as the summer progresses. Large fires are most likely to burn in July and August and few occur either during early summer or late summer.

This study further supports the understanding that landscape structure and human agency work in concert to influence spatial patterns of fire, and that the timing of fire events can be linked to climatic conditions that influence plant growth. Human activities that cause landscape fragmentation generally decrease fire size by creating discontinuous fuel sources (Christensen, 1993). Within specific areas of the Intermountain West (e.g. Idaho's Snake River Plains), however, human activities that facilitated the establishment and spread of exotic grasses have led to conditions where continuous fine-fuel sources exist, resulting in large and more continuous burns (Peters & Bunting, 1994). The present study suggests that along with the Snake River Plains region, several other regions have probably undergone an increase in fire size as shown by the clustering of large fires in areas dominated by exotic grasses. Further, since the exotic annual grass/wildfire cycle is driven by positive feedback (i.e. post-free recovery is dominated by quickly-maturing flammable exotic annual grasses to the exclusion of other, perennial species), we should expect these areas to be repeatedly affected by large fires in the future.

Fire-control management has traditionally been based on sophisticated models that provide near real-time forecasts, but were not designed to aid resource allocation prior to the fire season. Thus, determining fire-season behaviour a priori based on preferred locations and a single antecedent moisture index could be coupled with short-range forecasts to aid in fire control.

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